ATMOSPHERIC CHANGE, FORESTS AND BIODIVERSITY

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Dr Richard Hebda
Curator of Botany and Earth History
Royal British Columbia Museum
and
Biology and School of Earth and Ocean Sciences
University of Victoria

ABSTRACT

Predicted atmospheric change, mainly climate change, will have profound effects on the biodiversity of Canadian forests. Predictions derived from forest models, responses of species and ecosystems related to modern ecological characteristics and paleoecological studies suggest large-scale, wide-ranging changes from the biome to physiological levels. Paleoecological analogues in B.C. and other parts of Canada reveal that major changes must be expected in forest composition, range, structure and ecological processes. In B.C., past warmer and drier climates supported a different forest pattern, including forest types with no modern analogue. This produced dramatically different disturbance regimes, specifically more fires, and affected tree growth rates. The relationship of forests with non-forest habitats, especially wetlands and grasslands was different suggesting implications for wildlife biodiversity. British Columbia's Forest Practices Code prescribes guidelines for biodiversity objectives but ignores the issue of atmospheric change. This omission may result from a lack of understanding of the profound potential effects of atmospheric change on forest biodiversity in the next harvest cycle and lack of mechanisms to assess impacts and develop management strategies for specific sites. An example of a simple paleoecological assessment method involving pollen ratios is proposed.

1. INTRODUCTION

Atmospheric change may impact biodiversity at several levels ranging from effects on an individual's physiology, through genetic composition and geographic ranges of species to character and distribution of forest biomes (Melillo et al. 1990, Pollard 1992, Hebda 1994, Munn 1996). Though there is acknowledgement of the staggering potential ecologic, economic and social impact of climate-related biodiversity changes, there appears to be little progress in developing an understanding of specific impacts and practical strategies for adapting to change.

2. A CONCEPT OF BIODIVERSITY

My concept of biodiversity (Hebda and Whitlock 1996) is that of a living legacy with a unique history developed in situ; not simply the number of species, not simply a collection of genes kept in a zoo, or frozen in a bottle, and not simply rarity or strangeness. This concept encompasses ecological interactions of regional gene pools, which are the legacy of the unique biophysical history of a place. One advantage of this concept is that it allows investigation of the nature of specific elements of biodiversity (in the broad sense) and how they have responded to past climatic changes and evolved.

Paleoecological studies (Hebda 1995, Vance et al. 1995, Ritchie 1987) reveal that ecosystems (one aspect of biodiversity) change:

a) on a large scale (dominant species)
b) over large areas (across continents)
c) both suddenly and gradually.

Furthermore these studies indicate that mega-ecosystems (forest zones or biomes) have developmental (evolutionary histories) like species do, and in the context of geological time (last 2 million years) have relatively short duration. For example, in the coastal temperate forest region of northwestern North America there have been about 4 distinct major forest types since the glaciers left. Each forest type lasted on average 3,000 - 4,000 years (Hebda and Whitlock 1996).

These observations led me to propose the concept of the biogeochron, a time-dimensional ecosystem, central to understanding the relationship of atmospheric change and biodiversity (Hebda and Whitlock, 1996). Paleoecologists have long recognized intervals in the stratigraphic record, or in time, consisting of relatively uniform assemblages of fossils, and by inference representing ecosystems. By combining data from numerous types of subfossil or fossil groups of organisms, physico-chemical characteristics of sediments and interpreting them in the context of knowledge of modern eco-biotic processes, the biogeochron can be characterized. Once characterized, its origins and demise can be examined, and so too can the critical factors involved.

Change occurs through individual species' responses, not by ecosystem or biome migration (Davis 1981). One could mistakenly infer ecosystem migration because the range of dominant species shifts (often these are tree species) thus giving an impression that the coherent ecosystem has migrated. Paleoecological studies reveal that individuals (species) migrate.

For example, Hebda and Mathewes (1984) and Wainmann and Mathewes (1986) showed that western red cedar (Thuja plicata Donn.) became a co-dominant element of coastal temperate rainforests of northwestern North America only during the last 2000 - 5000 years. The other major arboreal forest species were already in place, and part of an earlier but different biogeochron. Furthermore, plant species and animal species evolve through the process of dispersal of sexual propagules and generate new ecological biodiversity.

These concepts are critical to the way we portray potential forest ecosystem responses to atmospheric change, whether the result of factors like acid rain or large-scale climatic changes (see also Harrington et al. 1991). Simply drawing maps outlining new boundaries/ limits of today's ecosystems is misleading, though still useful.

3. APPROACHES

Three broad approaches are available to examine the impact of atmospheric change on biodiversity:

SYSTEM ANALYSIS AND RESPONSE: This approach focuses on the physical, physiologic and biochemical processes within individuals and across a system (i.e. carbon fixation, respiration rates, fires etc. (see Melillo et al. 1990, Suffling 1995) and their relationship to climate. This perspective provides important insight into ecological processes but may be difficult to apply in practice to address questions of biodiversity (species and ecosystems). This approach is not reviewed in this paper.

MODERN RESPONSE CHARACTERISTICS: Here the focus is on the understanding of modern ecology of species and ecosystems, related processes and special requirements. With this information, one can estimate responses for various climatic scenarios (Melillo et al. 1990, Rizzo and Wiken 1992, Lenihan and Neilson 1995). I briefly discuss this approach in this paper.

PALEOECOLOGIC ANALOG: This strategy considers past conditions similar to those anticipated to occur in the future. It assumes future ecological processes similar to present ones. The approach allows us to envisage the nature of ecosystems and biodiversity as they existed under past atmospheric conditions analogous to those predicted for the future. The approach further allows us to examine the changes (cause and effects) and rates of change associated with the appearance and disappearance of the analog.

4. MODERN RESPONSE CHARACTERISTICS

If one knows the modern characteristics of an ecosystem, species, or population and its climatic (direct or indirect) limits/thresholds, then one may be able to predict its respective responses to change and develop response models. The simplest analysis consists of adjusting limits of range and recognizing new combinations as a result of the adjustment (see Emanuel et al. 1985 for a global example; Rizzo and Wiken 1992, and Lenihan and Neilson 1995 for Canadian examples).

A better approach involves using population-based forest growth models which incorporate geographic distribution, carbon storage, composition and other features and combine both Systems Analysis and Modern Response Characteristics approaches (Melillo et al. 1990, Burton and Cumming 1995). Such models show that forest structure, composition and geographic distribution might change. Such adjustments imply enormous impacts on the original biota and hence biodiversity.

Solomon (1986) ran such a model on eastern North American forests for 2xCO2 which provided insight into growth rates, die-back, range expansion and carbon storage. As far as Canadian biodiversity goes, it showed a) temperate deciduous trees invading the southern boreal forest, though with some delay caused by boreal conifers, b) a shift in the general pattern of forest vegetation. Such continental vegetation shifts have also been predicted by simply using modern climate-vegetation relationships (as you might for species-climate relationships) and re-plotting them according to post-atmospheric change climate distribution (Rizzo and Wiken 1992). Of course such reconstructions rely on sound climate models and modern vegetation-climate data.

Using this approach, Rizzo and Wiken (1992) predicted shifts in major ecological boundaries, changes in the character of broadly distributed ecosystems and the development of non-modern equivalent vegetation types. They noted the appearance of climatic conditions with no modern regional analogs. For example the Cool Temperate Ecoclimatic Province might expand dramatically into the eastern Boreal Province, a new Cool Temperate type might develop in the northwest interior, the Dry Continental Boreal Province might almost disappear and "Transitional Grassland" and "Semi-Desert" Ecoclimatic Provinces could appear. These non-analogue ecosystem types develop because the model predicts that Moderate Temperate Province type temperatures (warm) would occur with "Grassland" precipitation regimes.

Notably Rizzo and Wiken's (1992) exercise excludes the ecologically and climatically complex Cordilleran zone of British Columbia and Alberta. It is not a surprise that such general, geographically broad models are difficult to apply to the Cordillera. First the region's complexity defies sub-continental scale modelling. Second, national ecosystem classification schemes inadequately portray the region's complexity, hence themselves are inadequate. Extant climatic models for atmospheric change inadequately capture the complexity too; thus this kind of approach is difficult to apply effectively to the region.

Rizzo and Wiken (1992:53) make one assumption of concern in their account. They claim that "rapid wholesale changes in character (=biodiversity), in anything but the long term (50-200 years) would seem unrealistic". This conclusion ignores two important factors 1. the rate of climate change itself, especially with respect to extremes, and 2. thresholds in plant sensitivity to climatic factors. For example, extreme droughts may kill seedlings throughout a large range creating a gap in replacement and essentially leaving behind only a few senescing veterans. Such may be the case in Douglas-fir (Pseudotsuga menziesii (Mirbel) Franco) where Spittlehouse and Childs (1990) have observed low-rainfall related seedling death in post-disturbance plantings. Many other climate-related aspects of the normal growth cycle are similarly sensitive (Leverenz and Lev 1987).

Also, the paleoecological record reveals that sudden climatic and biodiversity shifts have indeed taken place. At the end of the last glaciation, sudden Younger Dryas cooling in parts of the Northern Hemisphere occurred in only a few decades and brought about major vegetation change (Peteet et al. 1993). Soon thereafter, just before 10,000 years ago, sudden warming ushered in the interglacial warm climates of the Holocene. Sudden ecosystem adjustments may have been the result of rapid immigration of competitively superior species or the expansion of in situ pre-adapted taxa (Hebda and Whitlock 1996).

The Modern Response Characteristic approach has proved very useful in helping visualize the potential impacts of atmospheric change especially over large areas. However, it has several weaknesses. For most species and ecosystems we know little about the factors that limit their geographic ranges. In particular, changes in species distribution take place in a complex ecological milieu and may be mediated via species-species interactions, or species-process interactions (i.e. fire) rather than the simple action of climatic limits.

Today's landscape has a different configuration than that upon which species and ecosystems evolved in the past. In many regions, the landscape is now profoundly fragmented by human activity. Furthermore, humans continue to interfere with the landscape, complicating natural species dispersal processes. Humans have also introduced exotic species into the ecological mix; predicting the response of such species may prove difficult.

The rate of climate change could be much greater than the potential of ecosystems and species to respond, whether by migration or evolution (see Harrington et al. (1991) for migration rates).

An important practical difficulty of the approach is that it is hard to apply to specific sites and management prescriptions. This particular disadvantage is particularly troublesome to on-the-ground forest managers. Their management prescriptions are usually stand- or landscape unit-based and they need to know specifically how their management unit might respond under a set of climatic scenarios. Furthermore, they need to know what the likelihood of impact is, so that risk management strategies can be developed. Simply knowing that the average range of a species or biome may shift is useful in a general way but difficult to apply except at the level of regional policy development.

5. PALEOECOLOGIC ANALOG

The value of using paleoecologic studies to assist in understanding climate change and predict impacts has been widely recognized (Melillo et al. 1990, Brubaker 1992, Jetté 1995) and has generated several international initiatives such as the Paleoclimate Model Intercomparison Project (PMIP) and the Past Global Changes Project (PAGES) (Jetté 1995). Paleoecologic studies help verify Global Circulation Models (GCM's) and provide insight into climatic processes.

The basis of the paleoecologic analog (paleoanalog) approach is the assumption that the climate-ecosystem experiment we may be facing in the near future has already been run in past millennia. Thus by "hindcasting" or using the past as a key to the future we can gain

important insight into impacts of climate change.

Paleoecologists, concerned about the issue of climate change, search the fossil records for ancient analogs representing climatic conditions predicted by climate modellers. Once examples of these conditions are found, they can be used to provide insight into the potential impact of climate change in a particular area. Paleoecologic methods and concepts are well described in several publications (Berglund 1986, Moore et al. 1991).

The paleoanalog approach has several important advantages. It

a) provides an actual final "state" which might result from atmospheric change,

b) provides insight into the path by which that state might arise and how quickly it might arise.

c) gives insight into "long-term", macro-scale processes not observable through short-term ecological studies and hard to estimate by using the limited species ecological data we have today.

d) provides examples of several climatic analogues (such as warm and dry, very warm and dry, warm and wet climatic states) because of the complex climatic history since deglaciation (see Hebda 1995 for an example).

e) provides site-specific, local-scale examples which can be compiled into a regional picture.

f) provides opportunities to examine independently many elements of biodiversity from the level of ecosystem to species to biochemical components.

g) can resolve responses on short and long temporal scales.

The paleoanalog like other approaches has several limitations:

a) The fossil record provides an incomplete account of an ecosystem because not all elements or species are preserved.

b) There are inherent problems in paleoecological analysis including differential production, transport and preservation of the raw material for the fossil record. These limitations also include the reworking of older fossil material into deposits forming at the time of existence of the ecosystem of interest. Notably many years of experience with reconstructing past ecosystems has led to methods by which these problems can be overcome.

c) Reliable paleoanalog reconstructions also depend on knowledge of ecological and biological characteristics and limitations of modern ecosystems and

species.

d) Ancient analogues cannot be assumed to be exact replicates of potential future conditions because: 1.future ecosystems may be derived from and exist under a different global solar radiation regime (ie the cause of warming is not the same), 2. preceding (source) biophysical circumstances are not the same, 3. there have been major human landscape disruptions since the time of the reference paleoanalogs.

Nevertheless the paleoanalog approach is a powerful tool for gaining insight into the impact of climate change on forests and their biodiversity because it provides data on specific sites, species, ecosystems and climatic regimes. Hebda (1997) combined paleoecological data with insights from systems models and analysis of modern response characteristics to examine the potential impact of climate change on biogeoclimatic zones of British Columbia and Yukon.

6. CLIMATE CHANGE, FORESTS, AND BIODIVERSITY IN BRITISH COLUMBIA

British Columbia is a large geographic area with enormous climatic and ecological diversity and extensive forest cover (Meidinger and Pojar 1991). The forest industry drives the economy of the province. Consequently the forests and their biodiversity provide an excellent case study to examine atmospheric change impacts.

Atmospheric change will impact forest at many levels from biome-wide effects to impacts on individual species (Hebda 1994, 1997). In the following section I apply data and concepts derived from paleoecological studies and knowledge of modern ecology and species distributions to suggest effects of atmospheric change on forest biodiversity in B.C.

Biome/ecosystem-wide impacts

Potential impacts will be of two sorts: 1. changes in distribution of mega-ecosystems, called biogeoclimatic zones in B.C. (Meidinger and Pojar 1991); 2. changes in the character of forested ecosystems.

Changes of the first kind involve shifts in the geographic range of zones by the replacement or disappearance of dominant and characteristic species. The following major effects might be expected:

a) Up-slope migration of tree lines into alpine elevations. The potential rate of expansion, especially the degree of resistance of the alpine environment to invasion by trees, is not well understood. Several authors (see Hebda 1995 for references), most recently Pellatt and Mathewes (1994), have demonstrated higher-than-present tree lines and other vegetation boundaries during warmer climates of the early to mid-Holocene in British Columbia. Spittlehouse (personal communication, September 1996) used zone climatic characteristics to estimate changes in elevational boundaries for south Vancouver Island if mean annual temperatures increased by 3°C.

b) Disappearance of forested ecosystems in regions of already warm and dry climate. Studies in the southern interior of B.C. reveal that grassland-steppe vegetation was much more widespread during warmer climatic regimes than today (Hebda 1982, 1995). Grassland vegetation occurred well up-slope and northward into areas now covered by Ponderosa Pine and Interior Douglas-fir (IDF) biogeoclimatic zones. The extent of the grassland steppe vegetation may have been such that it occupied much of what today is encompassed by the Interior Douglas-fir zone (Hebda 1997).

An upward shift in the grassland-forest ecotone may result in the connection of valley-bottom grasslands with alpine grasslands on south-facing slopes and research on this possibility is currently under way in the southern interior. In B.C. there may be serious negative impacts on native biodiversity with the entry of lowland weedy species such as knapweed species (Centaurea spp.) and cheatgrass (Bromus tectorum L.) into less affected alpine zones.

Forest retreat may also occur in coastal areas where there is little non-forest vegetation today. For example, Allen (1995) showed that meadow and rocky knoll vegetation was once widespread on parts of southeast Vancouver Island, now covered by Coastal Douglas-fir forest (CDF), during the warm and dry early Holocene 10,000 - 7000 years ago.

c) latitudinal migration of forest types and retreat of forest along precipitation gradients. These are basic types of changes to be expected with changing regional climatic regimes. Clearly the distribution of ecosystem types is primarily controlled by climate (see Meidinger and Pojar 1991 for B.C. data) and modification of climatic regimes must result in adjustments in forest zonation. British Columbia's environmental history has several examples of this phenomenon.

Allen (1995) showed how the limits of Coastal Western Hemlock-type forests moved eastward on south Vancouver Island displacing Coastal Douglas-fir-type forests in response to increasing moisture and decreasing temperatures in the mid to late Holocene. Similar adjustments were noted for the Fraser Lowland by Mathewes and Rouse (1975). Northward extension of ecological zones during warm climates is not yet well documented in B.C., largely because few studies have addressed this issue.

In Canada, northward extension of vegetation types during warm climate phases into colder regions is well established (Ritchie 1987). A recent volume of Géographie Physique et Quaternaire (Jetté 1995) reveals the effects of different climatic regimes on ecosystems/biodiversity on a subcontinental scale. For example, Vance et al. (1995) showed that in the Alberta to Manitoba region 6000 years ago, climate was 0.5°C to 1.5°C warmer than today and drier too. Compared to modern conditions 1. tree lines in the Rocky Mountains were 50-100 m higher. 2. forests occurred on high-elevation valley floors which today support wetlands (presumably because of drier climate). 3. the Boreal forest/grassland ecotone (parkland) extended 80 km farther north and 4. the northern boundary of the Boreal forest extended farther north.

Changes in Forest Structure and other Characteristics

Important changes will occur within stands and forest types too as individual species respond to changing atmospheric conditions. In some cases, species diversity may not change but the structure of the strata, species dominance, and overall stand physiognomy could be affected. Peteet's (1986) pollen and plant macrofossil analysis of Alaska's coast forests provides a good example of how the role of dominant species is affected by climatic factors. Today's forests arose not by species immigration; rather two relatively minor species, western *(Tsuga heterophylla* (Raf.) Sarg.) and mountain (Tsuga mertensiana (Bong.) Carr.) hemlock, expanded their role in the preceding Sitka spruce (Picea sitchensis (Bong.) Carr.) forest in response to climate change in the middle Holocene.

Two B.C. paleoecological studies provide clues into the way that structure might be affected by climate change. Banner et al. (1983) described the development of coastal forests with boggy openings near Prince Rupert, B.C. in response to increased moisture and cooling in the mid-Holocene. Warming and drying might be expected to reverse this pattern and result in stand closure. On the other hand, Allen (1995) showed that there was closing of dry openings and development of more closed forest stands in the Coastal Douglas-fir forests of south Vancouver Island during the same climatic period. Warming and drought will likely lead to more open stands. Generally in B.C. the trend will likely be to more open forests at mid to lower elevation and likely a more densely developed shrub stratum.

Climate change will impact individuals even if there appears to be little stand and ecosystem-level effect. The relationship between climate and tree-ring width is well known and exploited for proxy climate data (Fritts 1976). Spittlehouse (1996) illustrates the relationship between climatic factors and Douglas-fir growth. Laroque (1995) and Zhang (1996) demonstrate clearly that climatic factors have historically affected the growth of individual trees at high and low elevations on Vancouver Island. Less obvious effects will occur at the physiological level too (see Harrington et al. 1991).

Biodiversity issues are often viewed from the species perspective and "winner and loser" species should be expected in the climate change sweepstakes. According to the Holocene fossil record, coastal bog forest species will almost certainly become less abundant, whereas swamp forest species such as skunk cabbage (Lysichitum americanum Hulten and St. John) will increase in abundance (Hebda 1995).

On south Vancouver Island paleoecological analyses (Allen 1995) suggest that sea blush (Plectritis congesta (Lindl.(DC)), a parkland to open forest species, will likely extend its range and become more abundant under a warmer and drier climate. Rare B.C. forest species such as Oregon woodsorrel (Oxalis oregana Nutt.) (Ogilvie et al. 1984) may expand their range and role. Oregon woodsorrel is particularly interesting because it is especially abundant in the coniferous rainforests of adjacent Washington State, it responds positively to disturbance, and grows well in southwest B.C. gardens yet it remains rare in B.C. coastal forests.

Animal biodiversity is clearly sensitive to climate change too. Perhaps the most notable mammal with high risk to climate change is the extremely rare Vancouver Island marmot (Marmota vancouverensis (Swarth)). Higher tree lines and infilling of subalpine parkland openings could

be expected to have devastating negative impact on the animal's already restricted habitat. However our insights into this relatively well-studied animal may be still inadequate, for there is strong evidence that factors other than habitat availability (which is related to climate change) have contributed to the taxon's low numbers (Nagorsen et al. 1996). For example marmots move into openings created by logging forests (D. Spittlehouse, personal communication, September 1996).

On the other hand, a cavity-using species like the Pileated woodpecker *(Dryocopus pileatus* (Linnaeus)), might respond positively, if only temporarily, to climate change. Drought will lead to tree death and more snags, hence more food and more nesting sites for the woodpecker. These limited examples hint at the complexity of individual species' responses to climate change, and also point to how little we know about their biology.

Changes in ecological processes

Climate change will impact forest biodiversity by affecting system-wide ecological processes in addition to single-species effects. Different fire regimes are a certainty under warmer and drier climates of the future and have been prehistorically verified by paleoecologic investigations (Cwynar 1987, Vance et al. 1995). Landslide frequency may decline if susceptible sectors such as the perhumid west coast of Vancouver Island receive less rain. Flooding regimes will almost certainly be altered as snowpack and rainfall patterns become modified. Impacts on longer-term processes such as soil formation may take longer to show up, and perhaps moderate ecosystem response.

Adjacent ecosystems

Forest biodiversity depends strongly on non-forest neighbouring ecosystems. In B.C., wetland and alpine ecosystems will be highly sensitive to climate change (Hebda 1994). Small modifications in moisture availability could induce extensive wetland shrinkage and changes in character-- a prediction strongly supported by the paleoecologic record (Hebda 1995). Such changes would strongly impact forest-dwelling biota such as ducks and moose which depend on wetland habitats to survive. The forest/non-forest transition is critical to many mammals such as deer and bear too and any alterations of this ecotone would impact biodiversity. There are no doubt many more examples of the importance of non-forest environments to forest biodiversity, most of which we know little about.

FOREST BIODIVERSITY MANAGEMENT AND CLIMATE CHANGE IN B.C.

Considering the scale and diverse potential impacts on forest ecosystems, there appears to be little recognition and action related to this important issue. Uncertainty about climate change confuses and discourages forest managers from considering the issue (Spittlehouse 1996). With a planning horizon of 10 years, forest managers are little concerned about events 50-100 years in the future even if the next harvest may take place in the longer time frame. I believe that forest managers may not be aware of the real possibility that the effects may be extensive and profound, not just minor shifts or adjustments. Lack of data concerning impact on specific sites is a problem too, though several avenues of action are available (Spittlehouse 1996).

The Biodiversity Guidelines under the B.C. Forest Practices Code (Ministry of Forests and

B.C. Environment 1995) illustrate the lack of practical recognition of the issue. The Forest Practices Code Act requires management of forest resources to meet biodiversity objectives. Biodiversity management assumes that species and ecological biodiversity will be maintained if managed forests resemble those resulting from natural disturbance regimes (fire, blowdown, landslides etc). The guidelines use an ecosystem management approach based on Natural Disturbance Types (NDT's) which are largely derived from the modern distribution of biogeoclimatic units (Ministry of Forest and B.C. Environment 1995). These do not take into account potential climate changes in these regimes within the life time of the planned forest, despite the predictions of GCM's and widespread concern. I have already mentioned that natural disturbance types (fire regimes) have been considerably different under past warm and dry climates.

Research by my graduate students and me on south Vancouver Island (Allen 1995) suggest a simple and practical method for assessing one important characteristic, potential sensitivity, of forest ecosystems. The premise is a simple one: if the forests of an area were significantly different under past warmer and drier climate, then those forests should be considered potentially sensitive to climate change. On southeast Vancouver Island, sensitivity of Coastal Western Hemlock forests is easily established if those forests were once dominated by Douglas-fir, a drought and heat tolerant conifer. The relative abundance of western hemlock to Douglas-fir pollen, two easily recognized types, is established for a series of samples from a lake or bog core spanning the last 10 000 years. If the site showed a switch from Douglas-fir to western hemlock dominance in the past then it must be considered potentially sensitive. Allen (1995) identified the driest parts of the Coastal Western Hemlock zone to be sensitive, and on-going studies by my student K. Brown indicate that other subzones of the CWH may also be sensitive.

The conclusion from these observations is inescapable: forest biodiversity planning must take climate change into account. I note that the biodiversity guidebook (Ministry of Forests 1995) recognizes that changes to guidelines will be necessary as new data become available.

8. PRINCIPLES AND RECOMMENDATIONS

The insights gained from the three approaches that I have outlined about forest biodiversity and climate change lead to some important principles from which recommendations can be derived:

> Change is a natural process and is inevitable whether the result of human-induced atmospheric change or not.
>
> A steady-state "fossilized" or "museum" approach to biodiversity conservation is inappropriate.
>
> The new "biodiversity" should develop, as it has in the past, from the historically inherent (pre-European disturbance as much as possible) unique biodiversity of a region.

Biodiversity responses will occur primarily at the individual/species level, though ecosystem processes will be affected too.

If the models predict future climate well, impacts on biodiversity under atmospheric change scenarios will be as great, or greater than those since the melting of the last glaciers. In other words, the risk of impact is high.

Past biodiversity changes provide key insight into future responses, but extant biogeographic circumstances and profound human disturbance must be considered in the application of these insights.

Changes can and will be both gradual and sudden.

Recommendations

Scientists and forest managers must acknowledge the significant likelihood of climate change and its considerable potential impact. Lack of certainty and information cannot be an excuse for inaction because the risk of inaction is great (the precautionary principle).

Improved knowledge is critically needed in the areas of:
a. response characteristics of species, including all arboreal taxa, dominant shrubs and herbs and selected sensitive indicator taxa (rare plants, animals).
b. basic ecological processes and their climatic sensitivity
c. paleoenvironmental records to develop maps of potential sensitivity and understand long-term processes.

New experts in taxonomy and ecological processes must be trained to provide the skills to acquire new data and insight, and to counter recent attrition of professionals. Training must focus on young people and First Peoples, both groups with limited knowledge, considerable concern and a major role to play in the future of B.C.'s forests.

Climate change analysis and assessments must integrate data from the three main approaches; systems analysis, modern response characteristics and paleoecologic analogs to generate coherent and consistent predictions and develop effective strategies. Resources must be appropriately available for each of these avenues of investigation rather than focused, as they seem to be, on computer modelling.

Adaptive strategies for maintaining forest biodiversity should include:
a. the development of new native biodiversity/biogeochrons from native sources by identifying areas of ecosystems pre-adapted to warmth and drought and preserving them within an undisturbed ecological framework.
b. identification of "conservative" or complacent loci, through climatic mapping and cores in order to conserve extant biodiversity;

c. maintenance or re-establishment of connectivity of natural forest systems on the landscape via corridors and networks.
d. concentration not diffusion of human activity to allow natural in situ adjustment of biodiversity. Forest managers and society at large should adopt the "use only what is absolutely necessary" premise. A strictly conservative approach to natural resources is critical in times of change and stress.

9. CONCLUDING REMARKS

Much time and many resources are devoted to high-profile international and national meetings and events concerned with the climate change issue. Yet comparatively few resources are devoted where they are clearly needed; to collecting critical data and developing insight at the working level. To put it bluntly it is now time for a "Boots not Suits" approach (Hebda in Munn 1996).

Paleoecological and other types of analyses suggest that the risk of major impacts on forest biodiversity is great, and that the scale of impacts is considerable. The time for theoretical debate and bureaucratic discussion is past. We need data and understanding if we are ever to be prepared for the effects of climate change on forest biodiversity.

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